High-Resolution Structure of Bioluminescence Potential in the Nearshore Coastal Waters: Processes and Prediction/Zooplankton and Phytoplankton Contributors to Bioluminescence in Monterey Bay

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LONG-TERM GOALS

The long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and spatial variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data over relevant scales will enable better predictability of bioluminescence events in the nearshore coastal ocean.

OBJECTIVES

One of the primary objectives is to develop and integrate a bioluminescence autonomous underwater vehicle (AUV) capability into the existing observation networks to examine dynamics in coastal waters. This new platform is able to sample and define the relevant scales of bioluminescence and advance our understanding of the processes governing its temporal and spatial variability. This, combined with the forecasting objectives of the observational networks, will also provide a mechanism and framework for predicting bioluminescence potential in the coastal ocean. In addition to providing the basic science and ecology of bioluminescence, the AUV will provide important performance data that will help to fully characterize the instrument system for the Navy.

APPROACH

In order to address the objectives, above the following approaches were used. First, modify, design and fabricate bioluminescence bathyphotometer (BBP) for integration into a new generation of the Remote Environmental Measuring UnitS (REMUS) vehicle. Second, modify, design and fabricate AUV for measurements of nearshore coastal bioluminescence. Deploy the AUV in various coastal locations, some in areas of existing observational infrastructure (i.e. Monterey Bay, LEO-15). As this platform is new, a significant part of this project is also to develop the platform and define its capabilities for potential advances.

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14. ABSTRACT
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WORK COMPLETED

From October 2000 to June 2001, the new bioluminescence detector compatible with the REMUS AUV was designed and fabricated. The new nosecone combines the technology of the third generation bathyphotometer with the REMUS nosecone design to minimize drag with the front section acting as a light baffle, and more importantly to obtain water in the front of the vehicle that has not been previously stimulated. The bathyphotometer nosecone was also made to accommodate a number of other instruments of interest; a Seapoint fluorometer, an Ocean Sensors CTD and a Seapoint optical backscatter sensor. In March 2001, a REMUS training mission San Clemente Island. Training included general operation, mission planning, and vehicle maintenance on five missions. In July 2001, the nosecone was integrated (electronically, mechanically) with the REMUS vehicle at Woods Hole. Ballast testing and one field test also followed the integration to assess performance. Appropriate changes to the existing REMUS software were also made during this time to accommodate the newly integrated sensors. In July, 2001, the REMUS vehicle with the integrated bioluminescence nosecone was delivered to Rutgers University Marine Field Station (RUMFS). An AUV team was established and 3 initial successful test missions of the vehicle took place in daylight in Great Bay off of RUMFS. Since these initial field tests, the vehicle has successfully completed 23 missions for a total of approximately 350 km (Table 1). These missions have taken place on both coasts and have provided valuable bioluminescence data as well as performance data on the vehicle. From LEO-15, the vehicle was refurbished and additional batteries were installed. In January of 2002 a mission was conducted in Monterey in collaboration with J. Bellingham and S. Haddock (MBARI) as a demonstration of the vehicle in shallow waters. The following 11 missions were conducted off Cal Poly's new Marine Science station in San Luis Bay. Recently, 4 missions were conducted in Monterey Bay in support of the ongoing Autonomous Oceanographic Sampling Network (AOSN) effort.

Table 1. Summary of Bioluminescence REMUS AUV missions

Location	Date	Distance (m)
LEO-15, New Jersey	19-Jul-2001	1466
LEO-15, New Jersey	20-Jul-2001	1062
LEO-15, New Jersey	21-Jul-2001	1190
LEO-15, New Jersey	22-Jul-2001	13346
LEO-15, New Jersey	24-Jul-2001	1663
LEO-15, New Jersey	29-Jul-2001	12310
Monterey Bay, California	22-Jan-2002	22056
San Luis Obispo Bay, California	21-Mar-2002	12029
San Luis Obispo Bay, California	25-Mar-2002	11799
San Luis Obispo Bay, California	23-Apr-2002	14811
San Luis Obispo Bay, California	10-Jul-2002	14450
San Luis Obispo Bay, California	11-Jul-2002	43675
San Luis Obispo Bay, California	18-Jul-2002	7752
San Luis Obispo Bay, California	25-Jul-2002	7693
San Luis Obispo Bay, California	1-Aug-2002	7685
San Luis Obispo Bay, California	8-Aug-2002	7492
San Luis Obispo Bay, California	12-Aug-2002	7480
San Luis Obispo Bay, California	14-Aug-2002	7491
Monterey Bay, California	20-Aug-2002	42979
Monterey Bay, California	22-Aug-2002	31134
Monterey Bay, California	24-Aug-2002	44215
Monterey Bay, California	25-Aug-2002	34456
San Luis Obispo Bay, California	5-Sep-2002	315
TOTAL DISTANCE (km)		**348.55**

RESULTS

Result highlights obtained in fiscal 2001-2002 are reported here in order of the missions undertaken by the AUV. After deployments on the east coast the prior summer, the first west coast deployment was in January in Monterey Bay as a demonstration of the vehicles performance to collaborators at MBARI. The vehicle was able to collect data in 4 meters of water along the sandy west coast of

Monterey Bay in 3-meter seas. The vehicle mapped the fresher water discharge from the Elkhorn Slough and showed that the plume of estuary water hugged south of the estuary in a band about 200m wide. For the vast majority of the year, the vehicle was deployed off the new Cal Poly Marine Science Center in San Luis Obispo Bay to examine the dynamics in the nearshore and offshore horizontal gradients in bioluminescence over time. A system was developed whereby the acoustical navigational network is stationary (transponders at the ends of the three piers in the San Luis Obispo Bay) and the vehicle samples within and beyond the acoustic net and then returns to the net after completing the offshore transect. This has been a new approach to using the vehicle and has been successful in providing datasets not previously possible. This effort began as weekly deployments, however data appears to suggest a higher sampling frequency is required as the variation in both the distribution and intensity of bioluminescence is significantly different between weeks (data not shown). A nearby NOAA buoy provides the temporal context which to interpret the patterns of variation on a larger scale and from initial analysis it appears that major changes in wind direction, wave height and corresponding current patterns in the local area occur on time scales of approximately 4 days. This effort is continuing as it demonstrates the need for more sampling in order to adequately resolve the dynamics of bioluminescence in this nearshore system.

As seen in previous deployments on the east coast, the influence of tides has a significant effect on the concentration and dispersal of bioluminescent organisms along coastal frontal boundaries (Moline et al. 2001). On July 11th, 2002, the vehicle was deployed on the offshore transect and ran the transect repetitively for 12 hours. This date was chosen because it was the annual maximum for daily tide height difference, and therefore tidal current strength. Significant changes in the bioluminescence potential were seen over the tidal cycle that were not associated with the diurnal rhythm in bioluminescence. A longer transect is planned to examine the influence of regional circulation patterns on the nearshore frontal movements.

As a related piece of this project, the vehicle was deployed in conjunction with the Autonomous Oceanographic Sampling Network (AOSN) in August 2002. The aim of the larger project is to quantify the gain in predictive skill for principal circulation trajectories, transport at critical points and nearshore bioluminescence potential in Monterey Bay. The bioluminescence REMUS AUV was deployed repetitively over the course of a week to examine change in bioluminescence, partly to validate existing Lagrangian models for the region. As part of this larger effort, Cal Poly deployed the REMUS AUV on the north-south line, starting off the coast of Santa Cruz and oscillating between 3 and 40m 20km to MBARI's M1 mooring in the center of the Bay (2500m depth) and then returning to the Santa Cruz coast (at 20m for level ADCP measurements). This design is similar that that developed for deployments in San Luis Bay however the scale of these deployments was magnified by an order of magnitude. Figure 1 shows the first of four runs completed in Monterey Bay. Although this data has not been fully processed, what is clear is a frontal boundary approximately 5km from the start point. This result is exciting as it is very similar to a sharp frontal boundary found in the same location during the MUSE experiment and suggests that patterns of bioluminescence in this region may be repeated and largely be associated with water mass circulation. If true, this holds promise for the Lagrangian approach for this region.

As the AUV is a relatively new platform to examine nearshore dynamics, current missions have allowed us to assess and optimize the vehicles ability to sample biological fields. Although not directly related to a science/research question, it is important to avoid under sampling, which has critical implications for analysis and interpretation of data. Comparisons between AUV measured fields with ship profiles have shown orders of magnitude differences and have illustrated the inadequacy in coarse (>1km) profile sampling from ships for bioluminescence (Blackwell et al. 2003).

Flight optimization has also been pursued using theoretical data fields and has shown the vehicle's ability to resolve small-scale biological structure in its current configuration is most efficient at an ascent/descent rate of ~ 10m/min (Blackwell et al. 2003).

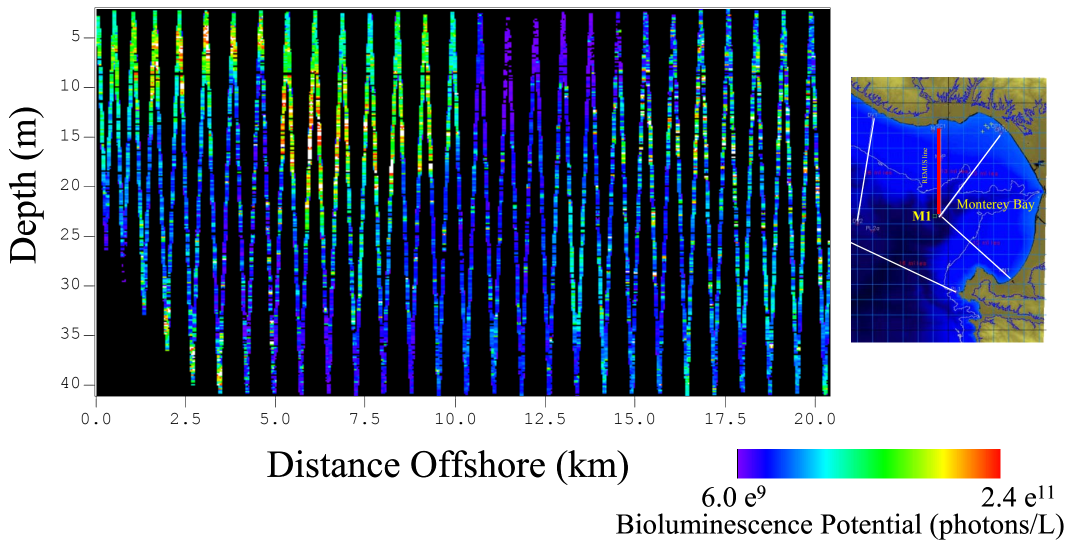

Figure 1. Vertical structure of Bioluminescence Potential along a 20km North to South transect in Monterey Bay on August, 20, 2002 measured from the Cal Poly REMUS AUV. Map inset shows the transect location in red.

As mentioned above, the AUV measures a concurrent suite of variables in addition to bioluminescence potential. Although bioluminescence has been shown to occasionally correlate to other parameters (i.e. fluorescence), these relationships are not universally applicable and often restricted to a particular location at a given time (Losee et al. 1985; Leiberman et al. 1987; Buskey 1992; Lapota et al. 1992; Swift et al. 1995; Losee et al. 1989). Data from this project have been used in a new approach to examine multidimensional relationships between bioluminescence and other physical and biological variables. Hierarchical clustering techniques were used to define unique water masses or water types based on temperature, salinity, density, fluorescence and optical backscatter. Subsequent water masses were then examined using Generalized Least Squares ANOVA to determine if the bioluminescence in those water types was different. Results were highly significant ($p<<0.001$) and demonstrated that clustering techniques were successful in defining unique water masses that were distinguishable from one another by their characteristic bioluminescent signal in both the Atlantic and Pacific oceans (Blackwell 2002). These results represent a more integrative approach than most previous efforts, which have restricted the application of quantitative diagnostic models to correlations of bioluminescence and one observed variable.

IMPACT/APPLICATION

The new bioluminescence AUV is functional and robust in the coastal environment. This project has demonstrated sustained use of this platform, has increased the vehicle's sampling performance and has advance the ability to detect fine-scale vertical/horizontal gradients in bioluminescence. This project

has pushed the capabilities of the vehicle and accompanying navigation system to a new level and deployed for durations longer than previous AUV efforts in very shallow coastal environments.

TRANSITIONS

This project adds a new high-resolution nighttime bioluminescence capability to observation networks (on both coasts of North America). Fine-scale vertical bioluminescent measurements coupled with ancillary physical/biological measurements off the coasts of New Jersey and California have improve the ability to predict bioluminescence events in the nearshore littoral regions of the marine environment. In addition to providing the basic science and ecology of bioluminescence, the AUV provides important performance data that will help to fully characterize the instrument system for the Navy. The REMUS vehicle has already transitioned to the Navy's EOD. The bioluminescence capability is presently being transferred to SPAWAR Systems, San Diego and collaboration with this AUV group is ongoing to transition performance and operational data from this project. This is the first time that this technology has been exclusively operated and maintained by scientists and not by engineers, and illustrates the ease in transitional use this technology.

RELATED PROJECTS

Projects that have either supported or benefited from this project through collaborations include; ONR-HyCODE program (N000149910197) with O. Schofield (Rutgers University), ONR-Biology/Chemistry (N00014-00-1-0008) with J. Case (UCSB), REMUS instrument development with C. VonAlt (WHOI), MUSE with S. Haddock (MBARI), SPAWAR Systems with R. Arrieta and B. Fletcher, and AOSN with a host of PI s (S. Haddock and J. Bellingham) and institutions (MBARI).

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